

# Cost-benefit of promising adaptations for resilient development in climate hotspots: evidence from lower Teesta basin in Bangladesh

Md. Arfanuzzaman, S. M. Tanvir Hassan and Md. Abu Syed

## ABSTRACT

It is very likely that climate change will increase the frequency and intensity of extreme events such as floods, flash floods, storms, heat and cold waves, riverbank erosion, and drought in the river basin of Hindu Kush Himalayan (HKH) region. This could mean detrimental impacts to the poor and marginal people in the lower Teesta basin (LTB) in Bangladesh. Though adaptation involves financial costs, the farmers' practicing adaptation in LTB experience diminished crop loss and damage. This study was aimed at assessing the promising adaptation practices, their economic return, and social welfare in the LTB through an extended cost-benefit analysis. The study suggests that among the adaptations, shallow tube-well (STW) based irrigation practice in both sandy and loamy soil has the highest marginal adaptation cost (MAC) but the lowest benefit-cost ratio (BCR). The deep tube-well (DTW) based irrigation practice generates superior benefits to the farmers compared to the STW based farming due to initial establishment by the government which is very expensive. Maize farming as an alternate and less resource consumptive cropping produces nearly five times higher economic benefits than the costs which can be acknowledged as the most profitable and resilient adaptation option in the LTB. Though MAC is relatively low for the short-duration variety (SDV) rice among the promising adaptations, its economic profitability is 62% lower than that of the maize cultivation. However, having higher BCR the maize cultivation generates US\$86 higher welfare to the farmers than the SDV rice which may strengthen the farmer's preference of maize cultivation over the SDV rice. It can be stated with high confidence that strategic adaptation planning, soft credit, technological advancement, and subsidized agricultural inputs will encourage the farmers to carry out adaptation options which may reduce climate-induced loss and damages for the farmers and build socio-economic resilience in the LTB and other similar areas of South Asia.

**Key words** | climate change adaptation, cost-benefit analysis, Hindu Kush Himalayan, lower Teesta basin, socio-economic resilience, weather extremes

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## INTRODUCTION

Climate change poses several risks to agricultural production, livelihood sectors, ecosystem services flow, and

economic prosperity at national, regional and global scale (Padgham 2009; Jiménez Cisneros *et al.* 2014; Tanner & Horn-Phathanothai 2014). As global warming over time is inevitable (Hertel & Lobell 2014), adaptation and climate risk management are crucial for unremitted growth and sustainable development (Adger *et al.* 2003; UNFCCC 2009;

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Amundsen *et al.* 2010; Watkiss *et al.* 2010; Noble *et al.* 2014). The Hindu Kush Himalayan (HKH) region of South Asia is one of the climate hotspots in the world (Krishnan *et al.* 2019; Bajracharya & Shrestha 2011) where 210 million mountain people and 1.3 billion plain people depend on the upstream water are exposed to multiple climate risks and socio-economic vulnerabilities (ICIMOD 2014; Hock *et al.* 2019). Increasing climatic variability and more frequent and erratic weather extremes or shocks could add susceptibility to poor households. This, in turn, might exacerbate the incidence, severity, and persistence of poverty, and water-food-energy security in the Himalayan sourced river basins in South Asia (Skoufias 2012; Arfanuzzaman & Syed 2017; Wijngaard *et al.* 2017).

Bangladesh was ranked the fifth most disaster-prone country in the world with a risk index of 19.6 (Kirch *et al.* 2017). The country is recognized as climate-vulnerable as it experiences devastating floods in north-east and central areas, cyclones and storm surges, and sea-level rise in the southern and eastern coastal areas, and widespread drought in the north-western region (Rabbani *et al.* 2010). The country has experienced higher temperature and decreased precipitation in the past three decades. This affects the water balance and its availability in many ways like changes in spatiotemporal patterns and variability of precipitation affecting the replenishment of water resources in the dry period and therefore, adverse impacts on all other sectors depending on water resources (Syed & Amin 2016). The agriculture sector plays a vital role in the economic development of Bangladesh in terms of Gross Domestic Product (GDP) contribution (15% in 2016) (BER 2017) and labor force engagement (48% in 2012) (Palanivel *et al.* 2016). The major crops of Bangladesh include rice (74% of crop area of 14.6 million ha), wheat (4.5%), jute (3.9%), rape and mustard (3.1%), vegetables and spices (1.6%), lentil (1.5%), chickling vetch (1.3%), potato (1.1%), sugarcane (1.1%), and chili (1.1%) (FAO 2013a). The country is found to be ranked among the top producers of jute (2nd), rice (4th), tropical fruit (6th), and potato (7th) in the world (FAO 2013b).

Poor and small-scale farmers of Bangladesh are most likely to be severely affected by climate change impacts due to their high dependence on agriculture for sustaining their livelihood activities (MoEF 2005; Gain *et al.* 2012;

Huq *et al.* 2012). The multifaceted and combined effects of climate and non-climate related change are manifested by the overall low adaptive capacity of smallholder agricultural communities to withstand climate change impacts (Lim *et al.* 2004; MoEF 2005). Climate-resilient agriculture, optimum natural resource harvesting and management, technological advancement, and alternative livelihoods are being considered as highly momentous adaptation options for the climate-vulnerable hotspots around the HKH dependent river basins. Extreme events such as floods, flash floods, thunderstorms, hailstorms, erratic rainfall, widespread drought, heat, and cold waves are common climate-induced disasters that adversely affect crop production and livelihood activities in the HKH sourced lower Teesta basin (LTB) in Bangladesh. Furthermore, overwhelming sand deposition on agricultural fields during floods reduces the soil fertility in the LTB area. While decreasing water levels in the Teesta river combined with irregular rainfall, infrequent precipitation during the dry season lead to resource strains for poor farmers to cultivate regular crops in the sandy and sandy loam soils of LTB. In this backdrop, the endeavor has been made in this study to find out appropriate and cost-effective adaptation options in the agriculture sector of the LTB with a view to reducing climate susceptibility and increasing economic resilience of poor and marginal farmers.

National Adaptation Programme of Action, Bangladesh Climate Change Strategy and Action Plan, Country Investment Plan for the environment, forest and climate change sector, and Delta Plan are considered the major climate change policy and strategic pillars for Bangladesh. They have addressed climate risks, impacts, vulnerabilities, and national level adaptation needs and priorities through forceful scientific knowledge and evidence (GoB 2010; Vij *et al.* 2017). The broader objectives of these national policy documents are to integrate potential adaptation measures into overall development planning processes, and build resilience to climate change, while promoting sustainable and inclusive development in Bangladesh (MoEF 2009; ADB 2011). Apart from these national efforts and initiatives, community-level adaptations are also very crucial to build climate resilience at the micro-level (Chambwera *et al.* 2011). Though there are a good number of success stories available at the grassroots level adaptations, the financial

and social benefit and cost-related information of these adaptation practices are largely unknown which obstructs the integration between micro and macro-level adaptation planning. In this circumstance, this study dedicates its effort to generate evidence-based versatile knowledge on community-level adaptation options and their cost-effectiveness and socio-economic viability in the LTB in northwest Bangladesh.

To attain this objective, our study has examined the most promising adaptation practices, their economic cost and socio-economic benefit in the LTB where the communities frequently affected by multiple climatic stressors. Then we estimated the magnitude of farmers' welfare and opportunity cost and benefit of adaptations for in-depth assessment and evidence generation. As costs and benefits of adaptation options are very worthy nowadays to assist planners and practitioners in identifying the most suitable interventions for reducing micro-level vulnerability and advancing resilience (WB 2011; ADB 2013; Westphal *et al.* 2013; ECONADAPT 2015). This study has adopted an extended cost-benefit analysis approach in examining the socio-economic feasibility of promising adaptations in the LTB and addresses their policy aspects for upscaling and out scaling for wider progress in development. Further, the study develops an adaptation decision support matrix containing the diversified information on social and economic aspects of widely practiced micro-level adaptation options which will enable farmers, institutions and policymakers to profitable adaptation-led resilience planning for combating climate change impacts in the agriculture sector of Bangladesh and HKH region as well. This study would further contribute to the policy planning of upscaling and out-scaling of the adaptation practices at other regions of the Global South.

## MATERIALS AND METHODS

We have adopted the methodology developed by WB (2008) to evaluate the cost-benefit of promising climate change adaptations in the LTB in Bangladesh. When assessing the costs and benefits of adaptation options, many approaches are proven to be effective in the broader context of national, regional, sectoral and micro-level planning and

management (WB 2011). According to the UNFCCC (2011) and GCCASF (2011), three most commonly used techniques for adaptation assessment are: (i) cost-benefit analysis (CBA); (ii) cost-effectiveness analysis (CEA); and (iii) multi-criteria analysis (MCA).

CBA assesses the benefits and costs of adaptation options in monetary terms. Whereas CEA identifies the least-cost option of reaching an identified target/risk reduction level or the most effective option within available resources, MCA assesses adaptation options against several criteria, which can be weighted, to arrive at an overall score. Apart from CBA, CEA, and MCA, several approaches such as strategic environmental assessments (SEA), environmental impact assessments (EIAs), risk-based approaches, and the Delphi method are also used for adaptation evaluation. As our paper intends to examine the financial and social feasibility of adaptation through the quantitative lens, the CBA method along with decision-support matrix and real benefit measurement approaches are used to scrutinize the most practiced adaptation options in the LTB of Bangladesh.

Typically, CBA accounts for the economic return of different projects, programs, interventions or policies to be compared in order to determine which of the interventions yields a greater level of benefits in relation to the resources invested. Given that a variety of adaptations and development interventions is considered, it is indeed essential to know which of these are the most resource-efficient and cost-effective in producing high benefits for the people. Based on the findings of CBA, we can determine which adaptation should be dropped, improved and scaled up in favor of other more effective and beneficial interventions. Figure 1 illustrates the analytical framework of the adaptation assessment that is followed in this study. It shows how the necessary data has collected and adaptation evaluation has carried out to deliver a justifiable outcome and generate policy relevant evidence for flourishing socio-economic resilience in the LTB. It appears in Figure 1 that, beyond the CBA, the study adopted wage days, purchasing power and opportunity cost analysis that further assist the stakeholder in making effective decisions and supporting the welfare-enhancing policymaking for the farmers.

Three tools such as the internal rate of return (IRR), net present value (NPV) and benefit-cost ratio (BCR) usually

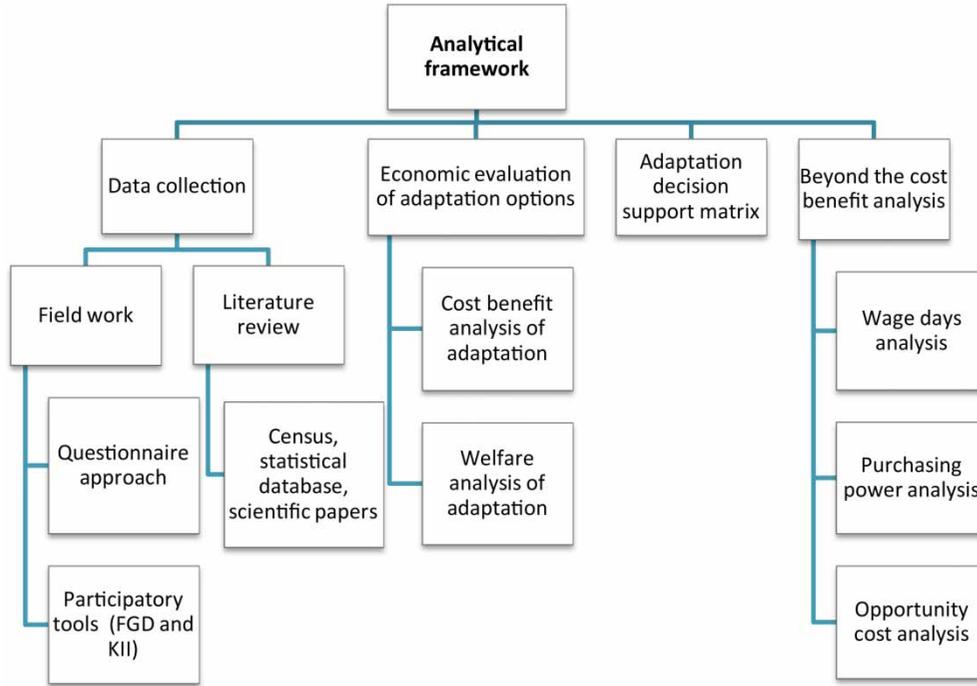


Figure 1 | Analytical framework of the study.

used in the CBA to measure the quantitative impacts and benefits of an intervention (WB 2008; McAllister 2014).

$$IRR = 0$$

$$= CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \dots + \frac{CF_n}{(1+IRR)^n} \quad (1)$$

where  $CF_0$  = initial investment;  $CF_1, CF_2, \dots, CF_n$  = cash flow;  $n$  = period,  $IRR$  = internal rate of return.

While (Magni 2011)

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \dots + \frac{C_T}{(1+r)^T} \quad (2)$$

where  $-C_0$  = initial investment;  $C$  = cash flow at different time;  $r$  = discount rate; and  $T$  = time/duration.

$$BCR = \frac{PV_b}{PV_c} \quad (3)$$

where  $PV_b$  = present value of benefits; and  $PV_c$  = present value of costs. The  $PV_c$  is the summation of all costs (total

cost,  $TC$ ) involved with specific adaptation. The formula of  $TC$  estimation is then:

$$TC = \sum_{i=1}^n IC_i$$

or,  $TC = IC_1 + IC_2 + IC_3 + \dots + C_n \quad (4)$

Similarly, the present value of benefits can be described as a summation of all associated benefits of an adaptation. The equation for estimating the total benefits is furnished as follows.

$$TB = \sum_{i=1}^n DB_i$$

or,  $TB = DB_1 + DB_2 + DB_3 + \dots + DB_n \quad (5)$

Due to the nature of the adaptation options in the LTB and unadoptability of  $IRR$  and  $NPV$  coupled with the unavailability of required data, the  $BCR$  approach is considered in this study for performing CBA exercise. The  $BCR$  is a ratio of the present value of the flow of benefits to the present value of the flow of costs of a measure. The  $BCR$  signifies the overall value for money. If it is greater

than 1, the adaptation measure makes a positive net contribution to the welfare and vice versa.

For the welfare measurement of the farmers, sellers, and society of the LTB, the following equation has been estimated.

$$\text{Farmers welfare (FW)}, FW = RP_f - AP_f \quad (6)$$

Here,  $RP_f$  denotes the reservation price of the farmers; and  $AP_f$  indicates the actual payment made by the farmers.

$$\text{Sellers welfare (SW)}, SW = RP_s - AP_s \quad (7)$$

Here,  $RP_s$  is the reservation price of the sellers and  $AP_s$  is the actual payment received by the sellers. It is also worthy to look over the situation of social welfare along with the farmers' and sellers' welfare. This will enable us to reveal and appraise how much welfare the adaptation options are adding to society.

$$\text{Social welfare (SoW)}, SoW = SW + FW \quad (8)$$

Further, in order to inspect the time benefit of adaptation, the number of wage days enjoyed has been estimated in response to a specific adaptation.

$$\text{No. of wage days enjoyed} = \frac{TR_{cp}}{DW_{sw}} \quad (9)$$

where  $TR_{cp}$  represents the total revenue receipt from a cropping period; and  $DW_{sw}$  is daily wage received for the substitute work.

Data collection and quantification of the necessary information were performed based on the participatory research method such as Focus Group Discussion (FGD) and Key Informant Interview (KII). The production loss is estimated based on the crop loss per unit of land due to different extreme events. The study excludes all types of fixed costs such as tube well installation cost in the revenue and cost consideration in the CBA. As the cost of deep tube-well installation is not directly covered by the farmer's pocket it is justifiable to include this in the provider's cost component. All other measurable direct and non-fixed

costs and benefits are reflected in the cost and revenue consideration in the study.

Figure 2 demonstrates the LTB area where the study is carried out. It appears that both India and Bangladesh share the Teesta river basin. The total length of Teesta is approximately 366 km out of which 117 km lies in the Bangladesh part (Arfanuzzaman & Ahmad 2016). In addition, about 8.5 million people live in the upstream Teesta river basin in Sikkim and the West Bengal state of India while about 21 million people live in the downstream region of Bangladesh (LTB). Figure 2 further indicates that the LTB of Bangladesh covers a part of the northwestern region of the country that passes through Lalmonirhat, Rangpur, Nilphamari, Kurigram and Gaibandha districts.

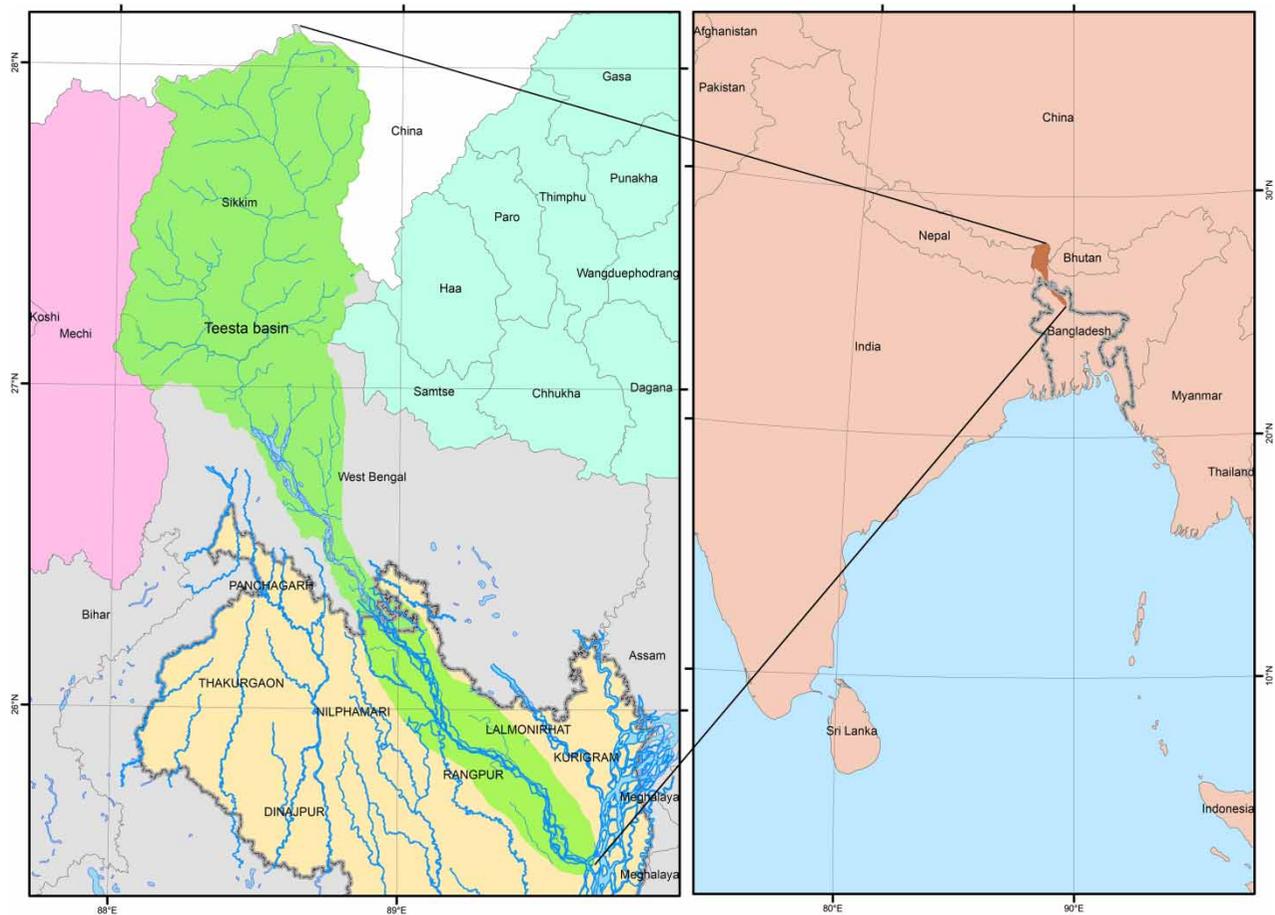
## RESULTS AND DISCUSSION

### Climate stresses and adaptation practices

The LTB of Bangladesh experiences multifaceted climate stresses in different seasons throughout the year. These climate stresses affect the livelihood sectors including agriculture, fisheries, and livestock in different ways. Table 1 represents the most common climate-induced stresses, their impacts on agriculture-related livelihoods and natural resources in the LTB. Climate extremes distress the crop agriculture, farming system, land use pattern, crop productivity and livelihood activities in the LTB. Besides, crop loss and damage are also emerging perilously in this region, which adversely distress the socio-economic conditions of the poor and marginal farmers and impeding their aptitude to fulfill the water, food, energy, and health demands making them socio-economically vulnerable.

### Selection of most practiced adaptations for CBA

As presented in Table 1 there are a good number of agricultural adaptations practiced by the people of the LTB. Since the cost-effectiveness, climate resilience, and economic appraisal of these adaptation practices are not available to the community, farmers, institutions and policymakers, the



**Figure 2** | The Teesta River Basin; lower Teesta basin lies mostly in Bangladesh.

study considers most practiced adaptations for the economic evaluation. These are: (i) short duration variety (SDV) rice; (ii) alternate cropping (AC): maize; (iii) deep tube-well (DTW) based irrigation; and (iv) shallow tube-well (STW) based irrigation.

### Appraisal of short duration variety (SDV) rice

To protect the crop from extreme weather events, the farmers of the LTB apply SDV rice during *boro* cropping period. The SDV allows farmers to harvest the crop earlier compared to the traditional type of variety. Table 2 demonstrates that farmers get 3.5 tons per ha from SDV rice and sell at US\$210 per ton (8.5 per mound). The total production cost of SDV rice is estimated US\$430 per ha which generates revenue US\$735 for the same. Farmers breed net

revenue US\$305 per ha by adopting SDV rice along with ensuring crop protection from climate-induced weather extreme. During the *boro* harvesting period, nearly 50% of crop damage occurs due to storms which have a market cost of US\$370. SDV rice enables farmers to avoid such damage and sustain crop production under such adverse effects of climate change. The total share of SDV rice (seed's current market price) is only 1.7% of total production cost which enables the farmers to carry out low-cost adaptation practices and overcome large-scale crop damage. Further, the BCR is found 1.7 for SDV rice production indicating US\$1 investment in this adaptation option produces US\$1.7 return to the farmers. If SDV rice is not adopted in the rice production system, the farmers experience an economic loss of US\$370 per ha.

**Table 1** | Climate change impacts and adaptation in the lower Teesta basin (LTB)

Major climate stresses	Impact	Adaptation practices
Drought	<ul style="list-style-type: none"> <li>• soil fertility loss</li> <li>• crop loss and damage</li> <li>• lower yield</li> <li>• plant dying</li> </ul>	<ul style="list-style-type: none"> <li>■ intense irrigation (shallow and deep tube well based)</li> <li>■ short duration variety (SDV) rice</li> <li>■ alternate cropping (AC) (maize)</li> <li>■ mixed cropping (maize and potato)</li> <li>■ drought tolerant variety (DTV) rice</li> <li>■ early harvesting</li> <li>■ high yield varieties (HYV) rice</li> <li>■ use of chemicals, pesticides, and fertilizer</li> <li>■ crop diversification (CD)/multi-cropping</li> <li>■ mulching for vegetable cultivation to reduce water footprint</li> <li>■ minimum tillage rice cultivation through improved machinery to save water and energy</li> </ul>
Flood/flash flood	<ul style="list-style-type: none"> <li>• crop loss and damage</li> <li>• plant damage</li> <li>• lower yield</li> <li>• sand deposition/soil erosion</li> </ul>	<ul style="list-style-type: none"> <li>■ flood-tolerant variety (FTV) rice</li> <li>■ early harvesting</li> <li>■ SDV rice</li> <li>■ AC (maize)</li> <li>■ use of chemicals and fertilizer</li> <li>■ floating-bed farming</li> <li>■ change in cropping pattern</li> <li>■ tidal river management</li> </ul>
Thunderstorm/hailstorm	<ul style="list-style-type: none"> <li>• crop loss and damage</li> <li>• plant damage</li> </ul>	<ul style="list-style-type: none"> <li>■ early harvesting</li> <li>■ use of chemicals, pesticides, and fertilizer</li> <li>■ use of net/thin plastic surrounding the crop field to protect the crop from hailstorm</li> <li>■ alternate cropping</li> </ul>
Cold wave	<ul style="list-style-type: none"> <li>• lower productivity</li> <li>• crop damage</li> </ul>	<ul style="list-style-type: none"> <li>■ change the cropping pattern</li> <li>■ early harvesting</li> <li>■ use of additional chemicals, pesticides, and fertilizer for quick crop growth during the cold wave</li> </ul>

Figure 3(a) points out that the SDV rice-based cropping system generates US\$7.8 worth of welfare per ha for the subsistence farmers and US\$1.2 for the seeds sellers. As an effective and profitable adaptation option, the SDV rice constructs the social welfare of US\$9/ha for society. There is an adverse relationship between farmers' and the sellers' welfare. If other things remain unchanged, the rise in the sellers' welfare will cut the farmers' welfare and vice versa. In other words, a 10% decrease in the price level of SDV rice causes to escalate the farmers' welfare by 10% keeping the social welfare level constant. In the case of SDV rice, farmers' welfare is exceedingly higher than the sellers' welfare indicating the SDV rice is a highly farmer-friendly and

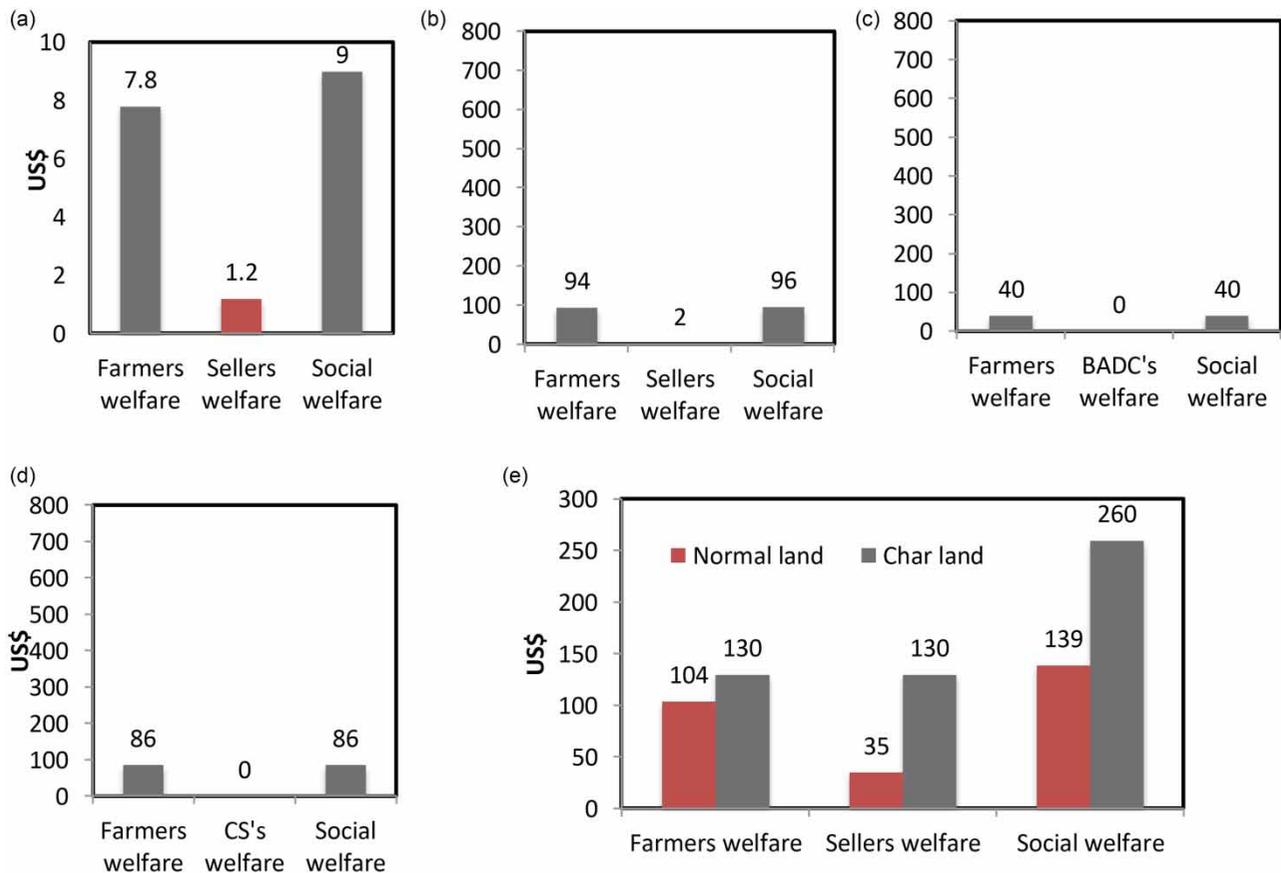
an economically gainful adaptation option which has a considerable impact on farmers' socio-economic resilience to climate change.

### Appraisal of alternate cropping (maize)

Alternative crops often have considerable prospect to emerge as a gainful adaptation option over the traditional crop practices. Farmers can enjoy a comparative advantage by adopting alternate crop cultivation in a certain ecosystem. In the LTB, maize was found as one of the most promising adaptations in the sandy and char land. As an alternative crop to rice, maize is popular and vastly

**Table 2** | Cost-benefit analysis of short duration variety (SDV) rice (BR-33) and alternate cropping (maize, variety *Kanak*) during *rabi* season

Parameters	SDV rice (BR-33)	AC (maize)
Total production cost (US\$/ha)	430	215
Total revenue (US\$/ha)	735	1020
Total production (ton/ha)	3.5	6
Selling price (US\$/ton)	210	170
Net revenue (US\$/ha)	305	805
Benefit-cost ratio (BCR)	1.7	4.7
Share of adaptation cost on total production expenditure	1.7%	10%
Crop damage due to extreme weather (storm)	50%	55%
Maximum willingness to get BR-33 (rice)/ <i>Kanak</i> (maize) seed (US\$)	0.75/kg, 15/ha	9.6/kg, 116/ha
Current market price of variety BR-33 (rice)/ <i>Kanak</i> (maize) seed (US\$)	0.40/kg, 7/ha	1.8/kg, 22/ha
Minimum seeds selling price of the vendor (US\$)	0.30/kg, 6/ha	1.7/kg, 20/ha
Duration of production (days)	100	120
Irrigation requirement per cropping period	8–10 times	3–4 times
Cost of inaction (US\$)	370	551

**Figure 3** | Derived welfare level from: (a) short duration variety (SDV) rice; (b) alternate cropping (maize); (c) deep tube-well (DTW) installed by the government of Bangladesh (Bangladesh Agricultural Development Corporation-BADC); (d) DTW installed by co-operative society (CS) at private sector; and (e) shallow tube-well (STW) used in normal and char lands at private sector.

cultivated crops in the LTB of Bangladesh due to its higher economies of scale and having climate-smart farming attributes. The cropping period of maize is mid-November to the end of April. Maize is gradually replacing the high yield *IRRI* rice variety in the LTB. For the increased sand deposition on cropland due to seasonal and flash floods, it is not feasible to cultivate rice during the lean (pre- and post-monsoon) season. Hence, maize is a much-preferred crop nowadays to the farmers which more promising due to its lower irrigation requirement than the previously cultivated rice variety. If the land is sandier, maize cultivation entailed 8–10 times irrigation within a cultivation period. The other benefits of such adaptation are: (i) production of maize is higher than *IRRI* rice variety; (ii) production cost is lower than *IRRI* rice variety; (iii) poor and marginal farmers can avail seeds and fertilizer at due price from the seller and can pay after harvesting; (iv) along with maize some other crops such as onion, mustard, coriander can also be cultivated simultaneously as a companion crop. The crop residue of maize is also used to feed the livestock. People also use dried plants as fuel-wood for cooking. Farmers do not need to go to the marketplace to sell maize. Wholesalers/aggregators come to the farmlands directly and collect the crops. In addition, maize is an imperishable crop that can be stored for a long time with sun drying. Nowadays maize is used for nutrition uptake because smashed maize is being mixed with wheat flour, which offers better nutrition and calorie.

It is found from the CBA in Table 2 that the total production cost of maize is US\$215 per ha while the revenue is US\$1,020 per ha. Maize farmers generally get 6 tons maize per ha which has a market price of US\$170 per ton. From maize cultivation, farmers able to generate net profit US\$805 per ha which incurs a BCR of 4.7. This indicates that with US\$1 investment in maize farming, farmers gets US\$4.7 return which is nearly five times higher than the investment base. Though maize grows well in both sandy and loamy soil, it requires less irrigation due to its low water consumptive attributes and its deep rooting system which can get water from shallow groundwater. In a single cropping period, maize farmers need to provide 3–4 times irrigation to cultivate the crop which slashes the production cost drastically. Further, the cost of maize variety named *Kanak* is US\$1.8/kg and farmers can harvest the crop by

their day-to-day labor for which no additional labor is required. Whereas, the percentage of expenditure on seed is only 10% of the total production cost which keeps the adaptation cost lower and affordable. As the production inputs of maize and other costs are identical with rice production, a cost of US\$215 on *Kanak* variety of maize gifts farmers a revenue of US\$1,020. That enables marginal farmers to generate decent revenues as well as uplift their socio-economic conditions.

Maize produces substantial welfare for the farmers and little for the sellers. Figure 3(b) shows that per ha maize cultivation endows US\$94 worth of welfare to the farmers and US\$2 worth of welfare to the sellers. There is a large gap between the welfare level of farmers and seed sellers indicating the extensive profit margin of the farmers. Due to higher return and low input cost of the maize farming, maximum welfare goes to the farmers' side. As per ha maize production generates a higher level of social welfare, there is enough room for welfare redistribution between the sellers and farmers keeping the total welfare level of the society constant.

### Appraisal of deep tube-well (DTW) based irrigation

The DTW is considered as a blessing to the resource-poor farmers of the drought-prone LTB as well as the northwest region of Bangladesh. Due to low surface water availability, farmers have no effective option for irrigation-based cropping practices. Like in other regions, the Bangladesh Agriculture Development Corporation (BADC) installed several DTWs in the LTB with a view to providing uninterrupted and low-cost irrigation facilities to the poor and marginal farmers. This fosters adaptation action and green revolution in the DTW coverage area. Table 3 shows that the total cost of DTW installation is US\$24,390 for BADC which economic life is at least 10 years. The total production cost of rice cultivation is estimated at US\$496 in the LTB where US\$75 needs to be spent for the DTW based irrigation. Based on the current market price of the paddy, the net revenue is calculated as US\$325 per ha for rice production. Here, the benefit-cost ratio (BCR) is US\$1.7, indicating US\$1 spending on BADC-DTW based cropping system generate a nearly double return to the farmers.

**Table 3** | Cost-benefit analysis of deep tube well installed by Bangladesh Agricultural Development Corporation of Government of Bangladesh (BADC-DTW), DTW installed by co-operative society (CS-DTW), shallow tube-well at char land (STW-Char) and STW at normal land (STW-Normal)

Deep tube well (BADC) based production	BADC-DTW US\$	CS-DTW US\$	STW-Char US\$	STW-Normal US\$
Fixed cost (Total installation cost)	24,390	1,464	244	244
Cost of submersible pump/tube-well pump	6,100	854	146	146
Labour, boring, pipe, and transport cost	7,320	610	98	98
Electricity connection, and appliance cost	6,100	–	–	–
House for pump cost	2,440	–	–	–
Total irrigation cost (per ha)	75	34	520	208
Total production cost (per ha)	420	424	332	332
Total revenue (per ha)	820	819	910	824
Net revenue/benefit (per ha)	325	361	58	284
Benefit cost ratio (BCR)	1.7	1.8	1.07	1.5
Total production loss due to drought	70%	75%	95%	70%
Share of adaptation cost on total production expenditure	15%	8%	61%	39%
Farmers maximum willingness to pay for irrigation (per ha)	115	120	650	312
BADC/CS/owner's minimum willingness to receive (per ha)	72	34	390	173
Economic lifetime of tube-well (years)	10	7–8	4	4
Cost of inaction	575	614	865	577

During dry (pre-monsoon) and lean season (post-monsoon) drought appeared as the major climate extreme in the LTB. Drought occurs due to irregular rainfall, high temperature, and lower water discharge in the Teesta river which severely affects the soil moisture and crop productivity. To abate the adverse effect of drought on crop production, farmers need to irrigate cropland more frequently in a cultivation period. According to the farmers' experience, drought damages nearly 70% of the crop production in the LTB. The DTW dependent irrigation enables farmers to irrigate the land at low cost and produce crops more easily. The share of the DTW based irrigation as adaptation expenditure is estimated at 15% of total production cost. Otherwise, farmers need to sacrifice US\$573 if this adaptation is not adopted in the water scarce season (dry and lean period).

Figure 3(c) suggests that the deep tube-well based irrigation produces US\$40 welfare per ha for the marginal farmers of the LTB. Whereas as a government-owned irrigation provider BADC attain no welfare against their service. Hence, the total welfare is US\$40 which entirely goes to the farmer's level. If the price was negotiated between farmers and BADC, then BADC may have the opportunity to

generate some welfare. In the present system, welfare is only concentrated on the farmers. If BADC attempts to maximize its welfare, the farmers need to sacrifice their welfare level. As the government provides subsidies to the BADC for the irrigation service, the irrigation scheme has no objective for profit generation, therefore, farmers can maximize their welfare and receive irrigation at a truncated cost.

In the LTB, the existence of a few co-operative society (CS) based DTWs can be found in different parts that are running through direct participation of the farmers. The member of the CS is responsible for the maintenance and management of the DTW. The member farmers usually get irrigation facilities at a cheaper price which is found lower than the price of BADC in most cases. Table 3 shows that the total installation cost of CS based DTW is US\$1,464 where tube-well cost is US\$854, and the installation-related cost is US\$610. The cultivation cost of rice is US\$424 per ha and farmers need to pay an irrigation fee of US\$34 to cultivate a single ha of land. For a CS-DTW based production, farmers need to bear US\$424 per ha as production cost while total revenue is US\$819. Farmers earn US\$361 net revenue per ha from this production practice which incurs

BCR 1.8. Alternatively, single dollar investment on CS-DTW based production provides US\$1.8 per ha signifying increasing returns to scale for the farmers. If farmers do not adapt CS-DTW, they must lose 75% of the crop during the drought period which has a market price of US\$4,614. The percentage of CS-DTW-based irrigation cost as an adaptation investment is 8% of the total production expenditure per ha which enables farmers to save US\$614. Though farmers are paying US\$34 per ha against this irrigation service they are willing to pay US\$120 per ha for this economically lucrative adaptation option. As the economic life of a DTW is 7–8 years, the CS needs to invest US\$854 for the new DTW which usually comes from the farmer's contribution.

Figure 3(d) shows that the CS-DTW based production practice fabricates US\$86 worth of welfare per ha for the farmers and zero welfare for the CS. As a CS is owned by the farmers' group and practices non-commercial norm, no welfare goes to the CS side. Besides, farmers' welfare and CS's welfare are reciprocal as farmers are the sole direct stakeholder of the CS's irrigation scheme. Consequently, social welfare will remain the same for all cases. If a CS tends to accumulate welfare, the level of welfare experienced by the farmers will be reduced. For the future economic sustainability of the farmers, a CS needs to accumulate some profit and welfare which will ease the burden of purchasing new DTW after the full depreciation of the existing one.

### Appraisal of shallow tube-well based irrigation

The easy installation and mobility feature allow the shallow tube-well (STW) to use in any type of land in the LTB. Farming of the *char* land in sandy soil requires more irrigation than the normal land in loamy soil which leads to increased production costs. Table 3 points out that the total installation cost of an STW is US\$244 for both *char* and normal land with US\$146 for the tube-well pump and the rest (US\$98) for installation related cost (labor, boring, pipe, and transport). Generally, farmers depend on rental irrigation from STW. The STW owner charges US\$1.5 per hour of irrigation service. The total cultivation cost for STW based farming is US\$852 per ha. Here, US\$520 is the irrigation cost which is 61% of the total production cost. STW based farming as an adaptation allows farmers to produce a net profit of US\$58 per ha. The BCR of this type of farming

is counted as only 1.07 demonstrating a very low marginal return for the farmers. According to the farmers, drought cause damage to 95% of the crop in the *char* and sandy land which has a market price worth US\$865. The estimation shows that US\$520 expenditure for adaptation saves US\$865 production loss per ha of the farmers.

The adaptation cost and benefit are quite different for the STW-based irrigation and cropping practices in the plain and normal land. Like *char* land the installation cost of STW is similar. Here, the total cost of rice production (irrigation US\$208 plus cultivation US\$332) is accounted as US\$540 in the normal land (Table 3). As less irrigation is required in the normal land compared to the sandy and *char* land, the percentage of STW-dependent irrigation cost is found inferior in the same. Whereas the total revenue of the STW-based farming is US\$824 per ha. In normal land, farmers enjoy net revenue of US\$284 which is higher to a large extent compared to the production practice in the sandy and *char* land. In a normal land, the STW based farming as an adaptation ensures a BCR 1.5 indicating US\$1 investment in this production system return US\$1.5 to the farmers.

In normal land, drought impacts 70% production loss per ha costing US\$577 at a current market price. The STW-based irrigation can save the entire crop loss if farmers can bear the US\$208 per ha for STW irrigation which is 39% of the total production cost of US\$540. Hence, in the normal land, the cost in the absence of adaptation is US\$577 while the benefit of adaptation is US\$284 per ha.

Figure 3(e) postulates that in normal land STW-based irrigation generates relatively superior welfare to the farmers for rice production. In normal land, farmers' welfare appeared US\$104 per ha while the seller's welfare is found US\$35 per ha. STW irrigation practice produces nearly three times welfare to the farmers than the seller's welfare. The total social welfare generated from STW-based irrigation is US\$139 in the normal land. Besides, in the sandy *char* land overall social welfare is found merely US\$260 per ha for the STW-based irrigation. As rice farming in *char* and sandy land is challenging due to unfavorable soil quality and require extensive irrigation, farmers' welfare is found considerably inferior to the normal land. Sellers' welfare is a little higher in *char* land compared to normal land.

**Table 4** | Decision support matrix for the adaptation options

Particulars (US\$)	SDV rice BR-33	AC Maize	DTW based irrigation		STW based irrigation	
			BADC	CS	Normal land	Sandy/char land
Net profit	305	805	325	361	284	58
BCR	1.7	4.7	1.7	1.8	1.5	1.07
Adaptation cost	7.2	22	75	34	208	520
Share on total production cost	1.7%	10%	15%	8%	39%	61%
Marginal adaptation cost	0.24	1.71	6	2.8	17	17
Farmers welfare	7.8	94	40	86	104	130
Social welfare	9	96	40	86	139	260
Adaptation benefit	371	551	575	614	577	865

### Adaptation decision support matrix

The adaptation decision support matrix (ADSM) explained by Table 4 shows the financially and economically feasibility of adaptation practices. It is also worth mentioning, that the total production expenditure and the contribution of adaptation costs are much higher for STW-based irrigation in sandy/char land which is estimated at US\$520 per ha. While the lowest share of adaptation cost is found for SDV rice which at only US\$7.2 per ha. The share of adaptation cost appears less than US\$100 for maize cultivation, BADC-DTW and CS-DTW, and SDV rice. The STW-based irrigation in both normal and sandy land accounts above US\$200 per ha for adaptation cost.

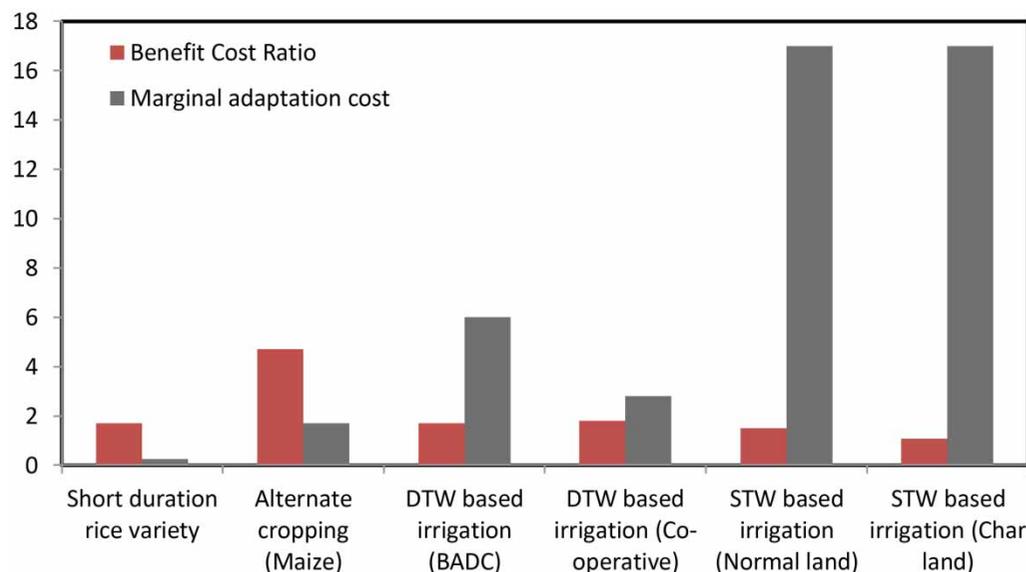
BR-33 as an SDV rice, maize as an alternative crop, BADC-DTW, and CS-DTW irrigation, STW-based irrigation in normal and sandy (*char*) land generates US\$305, 805, 325, 361, 284, and 58 net profit per ha, respectively. Here, maize as an alternative crop produces the highest profit per ha and STW-based irrigation in sandy land produces the lowest revenue per ha compared to other adaptation practices. On the other hand, 4.7, 1.8, 1.7, 1.7, 1.5 and 1.07 BCR are generated by the AC (maize), CS-DTW irrigation, SDV rice, BADC-DTW irrigation, STW irrigation in normal and sandy land, respectively. Among the adaptation options, AC (maize) ensures uppermost BCR per ha while STW based irrigation in sandy land produces relatively little BCR per ha. Further, farmer's welfare emerges higher for the STW-based irrigation in both normal and *char* land and AC (maize). In contrast, farmers' welfare is found the

least for the SDV rice, whereas CS-DTW and BADC-DTW irrigation-based irrigation generate some moderate welfare for the farmers. It appears that, though the BCR of both DTW and STW based irrigation in the normal land are similar to the SDV rice, their welfare level is remarkably higher than SDV rice.

Figure 4 demonstrates that among the adaptation options, marginal adaptation cost (MAC) is substantially higher for STW-based irrigation in both sandy and normal land which is estimated at US\$17 per irrigation. Comparatively, downward MAC is found for SDV rice and AC (maize). MAC for DTW based irrigation varies between US\$2.8 (CS) and US\$6 (BADC) per irrigation. The graphical representation of BCR and MAC denotes the adverse relationship between the two. When MAC is higher, the BCR is found to be lower for the adaptations and vice versa. Alternatively, MAC reduces the extent of BCR for the adaptation. If farmers intend to have a higher level of BCR as well as a generous economic benefit, the MAC needs to be reduced substantially which can be done through government subsidy, infrastructure development, low cost input and technological advancement to the farmers.

### Beyond the cost-benefit analysis

In this section, net revenue from the adaptation is assessed from other perspectives of economics such as purchasing power, equivalent wage days, unearned days and opportunity cost. Table 5 demonstrates the number of wage days,



**Figure 4** | Benefit-cost ratio (dark) and the marginal cost of adaptation (red). Please refer to the online version of this paper to see this figure in color: <http://dx.doi.org/10.2166/wcc.2020.130>.

**Table 5** | Number of wage days enjoyed, purchasing power and opportunity cost in response to net benefits of the adaptation options

	Net revenue (US\$)	No. of wage days enjoyed	Rice equivalent purchasing power (kg)	Unearned days	Opportunity cost (US\$)
SDV rice	311	86	576	14	50
BADC-DTW	323	90	598	30	108
CS-DTW	361	100	669	20	72
STW-Normal	283	79	709	41	148
STW-Char	58	16	107	104	374
Alternate cropping (maize)	783	217	1,450	-97	-349

unearned days and rice equivalent purchasing power against the net revenue per hectare (ha) in a cropping season per farmer. The estimates suggest that per ha net revenue from SDV rice protects 86 days of wage-earning and allows 576 kg of rice purchase. In other words, if any farmer cultivates SDV rice in 1 ha of land, s/he will earn equivalent to 86 wage days which is similar to the price of 576 kg rice. Further, as the cropping period of SDV rice is 100 days, farmers miss 14 wage days from such farming and here the estimated opportunity cost of the farmers is US\$50. Whereas DTW-based irrigation provided by BADC and CS protect 90 and 100 wage days correspondingly. The net revenue generated from these DTW-based adaptations equips farmers with the equivalent of 598 and 669 kg rice purchasing power per ha. Moreover, BADC-DTW irrigation

deprives farmers of 30 earning days which has an opportunity cost of US\$108/ha, whereas CS-DTW irrigation imposes 20 unearned days to the marginal farmers which incur US\$72/ha opportunity cost. In normal land, farmers get 79 day wages and 709 kg rice equivalent purchasing power by the adaptation benefit of the STW-based irrigation. On the other hand, it recommends 41 nonwage days per ha equal to approximately US\$148. In sandy *char* land, farmers get 16 wage days and are awarded 107 kg rice equivalent purchasing power by the adaptation benefit of the STW-based irrigation. Besides, it exerts 104 nonwage days per ha and extensive opportunity cost which is calculated US\$374. Similarly, alternate cropping such as maize farming offers 217 wage days and 1,450 kg rice equivalent purchasing power. Here, the net revenue of this adaptation

practice presents an additional 97 earning days which estimated opportunity gain is US\$349.

The STW-based irrigation (sandy *char* land) offers comparatively highest opportunity cost for the farmers which is more than double that of other adaptation options. Likewise, the lowest opportunity cost is found for SDV rice among the adaptation practices which is equivalent to US\$50. It is evident that maize as alternate cropping generates opportunity benefit equivalent to US\$349 per ha assuring the optimum gain to the farmers which helps them to become socio-economically resilient in the view of climate change impacts and multiple vulnerabilities in the LTB in Bangladesh. If marginal farmers, excluding maize farmers, engage themselves in other daily or monthly wage-earning activities their opportunity cost would be zero which would endow them much higher purchasing power and higher living standard.

## CONCLUSIONS

Frequent and severe extreme events under climate change impacts could lead to an increase in poverty in the lower Teesta basin (LTB) of Bangladesh which can be reduced to some extent by proper adaptation, planning, and innovation. The farmers practiced adaptations in the LTB experience reduced loss and damage and vice versa. The cost and benefits of the adaptation depend on the input cost, innovation, government support, and technological advancement. The study found among the adaptations, the shallow tube-well (STW)-based production practice in both sandy and regular land has the highest marginal adaptation costs and the lowest benefit-cost ratio (BCR). The deep tube-well (DTW)-based production practice generates superior benefits to farmers compared to the STW-based farming system. Maize farming as alternate cropping generates nearly five times higher economic benefits than the costs which can be termed as the most profitable and resilient adaptation option in the LTB. Though marginal adaptation cost is the least for the short-duration variety (SDV) rice, its economic profitability is 62% lower than the maize cultivation. However, having lower BCR, the SDV rice produces US\$51 higher social welfare than the maize cultivation. It deserves to specially mention that, while

generating a scanty economic return, the DTW- and STW-based irrigation save large loss and damage compared to other adaptation options. As maize farming offers a comparatively higher rate of return to the farmers, it may direct them to shift from rice to maize cultivation. In this circumstance, surplus maize and deficit rice production can take place which can lead to price distortion in the market. To avoid such a situation, suitable areas for maize and rice cultivation can be defined based on the landscape, ecosystem, and climatic condition, and natural resource availability and engage the private sector in supply chain improvement, crop processing, value addition, and storage facility enhancement.

It is evident that though all the adaptation options generate a positive economic return, they cannot be considered substantial or socio-economically resilient for the farmers of the LTB. There is enough room to make these adaptation options more profitable. Strategic adaptation planning, input subsidy, soft credit, effective crop insurance, and low-cost technology advancement can encourage the farmers to carry out such adaptation options during the extreme weather events which could help reduce loss and damage while building socio-economic resilience in the view of climate change impacts and vulnerabilities.

## DISCLAIMER

The views expressed in this work are those of the authors and do not necessarily represent those of the UK Government's Department for International Development, the International Development Research Centre, Canada or its Board of Governors, the Food and Agriculture Organization of the United Nations and Bangladesh Centre for Advanced Studies.

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## REFERENCES

- ADB 2011 *Adapting to Climate Change: Strengthening the Climate Resilience of Water Sector Infrastructure in Khulna*. Asian Development Bank, Philippines, Bangladesh, p. 40.
- ADB 2013 *The Economics of Climate Change in the Pacific*. Asian Development Bank, Philippines, p. 103.
- Adger, W. N., Huq, S., Brown, K., Conway, D. & Hulme, M. 2003 *Adaptation to climate change in the developing world*. *Progress in Development Studies* 3, 179–195.
- Amundsen, H., Berglund, F. & Westskog, H. 2010 *Overcoming barriers to climate change adaptation – a question of Multilevel Governance?* *Environment and Planning C: Government and Policy* 28, 276–289.
- Arfanuzzaman, M. & Ahmad, Q. K. 2016 *Assessing the regional food insecurity in Bangladesh due to irrigation water shortage in the Teesta catchment area*. *Water Policy* 18 (2). <https://doi.org/10.2166/wp.2015.072>
- Arfanuzzaman, M. & Syed, M. A. 2017 *Water demand and ecosystem nexus in the transboundary river basin: a zero-sum game*. *Environment, Development and Sustainability* 20 (2), 963–974.
- Bajracharya, S. R. & Shrestha, B. 2011 *The Status of Glaciers in the Hindu Kush-Himalayan Region*. International Centre for Integrated Mountain Development, Kathmandu, p. 140.
- BER (Bangladesh Economic Review) 2017 *Ministry of Finance*. Government of Bangladesh, Dhaka.
- Chambwera, M., Downing, T., Crawford, V., Dyszynski, J., Venton, C. C., Butterfield, R., Birch, T., Bezabih, M. & Loga, D. 2011 *Planning and Costing Agriculture's Adaptation to Climate Change – Synthesis Report*. International Institute for Environment and Development, London, p. 40.
- ECONADAPT 2015 *The Costs and Benefits of Adaptation: Results From the ECONADAPT Project* (P. Watkiss, ed.) ECONADAPT Consortium, Bath, p. 54.
- FAO 2013a *FAOSTAT: Commodities by Country*. Food and Agricultural Organization of the United Nations, Rome.
- FAO 2013b *FAOSTAT: Countries by Commodity*. Food and Agricultural Organization of the United Nations, Rome.
- Gain, A. K., Giupponi, C. & Renaud, F. G. 2012 *Climate change adaptation and vulnerability assessment of water resources systems in developing countries: a generalized framework and a feasibility study in Bangladesh*. *Water* 4, 345.
- GCCASF 2011 *Costing, assessing & selecting: Adaptation & mitigation: options & measures: module 6*. In: *Workshop Series on Mainstreaming Climate Change*. Global Climate Change Alliance Support Facility, Brussels.
- GoB 2010 *The Climate Change Trust Act*. Government of Bangladesh, Dhaka, p. 12.
- Hertel, T. W. & Lobell, D. B. 2014 *Agricultural adaptation to climate change in rich and poor countries: current modeling practice and potential for empirical contributions*. *Energy Economics* 46, 562–575.
- Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., Jackson, M., Kääb, A., Kang, S., Kutuzov, S., Milner, A., Molau, U., Morin, S., Orlove, B. & Steltzer, H. 2019 *Chapter 2: High Mountain Areas, IPCC Special Report on the Ocean and Cryosphere in A Changing Climate*.
- Huq, N., Hossain, Z. & Hasan, R. 2012 *'Climate Proofing' water resources development policy: the evidence from Bangladesh*. In: *Climate Change and the Sustainable use of Water Resources* (W. L. Filho, ed.). Springer, Berlin, Heidelberg, pp. 389–400.
- ICIMOD 2014 *Hindu Kush Himalayan Region*. International Centre for Integrated Mountain Development, Kathmandu.
- Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Döll, P., Jiang, T. & Mwakalila, S. S. 2014 *Freshwater resources*. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea & L. L. White, eds). Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.
- Kirch, L., Luther, S., Mucke, P., Prütz, R., Radtke, K. & Schrader, C. 2017 *World Risk Report: Analysis and Prospects 2017*. Bündnis Entwicklung Hilft, Berlin, p. 56. (an alliance of 11 organizations based in Berlin, Germany).
- Krishnan, R., Shrestha, A. B., Ren, G., Rajbhandari, R., Saeed, S., Sanjay, J., Syed, M. A., Vellore, R., Xu, Y., You, Q. & Ren, Y. 2019 *Unravelling climate change in the Hindu Kush Himalaya: rapid warming in the mountains and increasing extremes*. In: *The Hindu Kush Himalaya Assessment* (P. Wester, A. Mishra, A. Mukherji & A. Shrestha, eds). Springer, Kathmandu.
- Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E. & Huq, S. 2004 *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*. Cambridge University Press for United Nations Development Programme, Cambridge, p. 263.
- Magni, C. A. 2011 *Average internal rate of return and investment decisions: a new perspective*. *The Engineering Economist* 55 (006653). doi:10.1080/00137911003791856.
- McAllister, E. W. 2014 *Economics*. In: *Pipeline Rules of Thumb Handbook*, 8th edn (E. W. McAllister, ed.). Gulf Professional Publishing, Boston, pp. 673–721.
- MoEF 2005 *National Adaptation Programme of Action* (November 2005, ed.). Ministry of Environment and Forest, Government of Bangladesh, Dhaka, p. 46.

- MoEF 2009 *Bangladesh Climate Change Strategy and Action Plan 2009* (September, 2009, ed.). Ministry of Environment and Forest, Government of Bangladesh, Dhaka, p. 98.
- Noble, I. R., Huq, S., Anokhin, Y. A., Carmin, J., Goudou, D., Lansigan, F. P., Osman-Elasha, B. & Villamizar, A. 2014 Adaptation needs and options. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea & L. L. White, eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Padgham, J. 2009 *Agricultural Development Under A Changing Climate: Opportunities and Challenges for Adaptation, Joint Department Discussion Paper, Issue-1*. World Bank, Washington, DC, p. 198.
- Palanivel, T., Mirza, T., Tiwari, B. N., Standley, S., Nigam, A. & Luchsinger, G. 2016 *Asia-Pacific Human Development Report: Shaping the Future: How Changing Demographics Can Power Human Development*. United Nations Development Program, New York, p. 264.
- Rabbani, G., Rahman, A. A. & Islam, N. 2010 Climate change and sea level rise: issues and challenges for coastal communities in the Indian ocean region. In: *Coastal Zones and Climate Change* (D. Michel & A. Pandya, eds). The Henry L. Stimson Center, Washington, DC, p. 13.
- Skoufias, E. 2012 *The Poverty and Welfare Impacts of Climate Change: Quantifying the Effects, Identifying the Adaptation Strategies*. World Bank, Washington, DC, p. 146.
- Syed, M. A. & Amin, M. A. 2016 [Geospatial modeling for investigating spatial pattern and change trend of temperature and rainfall](#). *Climate* **4**, 21.
- Tanner, T. & Horn-Phathanothai, L. 2014 *Climate Change and Development*. Routledge, Taylor & Francis Group, London.
- UNFCCC 2009 *Conference of the Parties: Report of the Conference of the Parties on its Fifteenth Session, Held in Copenhagen From 7 to 19 December 2009: Part Two: Action Taken*. United Nations Framework Convention on Climate Change, p. 43.
- UNFCCC 2011 *Assessing the costs and benefits of adaptation options: an overview of approaches*. In: *The Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change*. United Nations Framework Convention on Climate Change, Nairobi, p. 52.
- Vij, S., Moors, E., Ahmad, B., Arfanuzzaman, M., Bhadwal, S., Biesbroek, R., Gioli, G., Groot, A., Mallick, D., Regmi, B. & Saeed, B. A. 2017 Climate adaptation approaches and key policy characteristics: cases from South Asia. *Environmental Science & Policy* **78**, 59–65.
- Watkiss, P., Downing, T. E. & Dyszynski, J. 2010 *Analysis of the Economic Costs of Climate Change Adaptation in Africa*. United Nations Environmental Programme, Nairobi.
- WB 2008 *The Economics of Adaptation to Climate Change: Methodology Report*. The World Bank Group, Washington DC, p. 18.
- WB 2011 *Economics of Adaptation to Climate Change*. The World Bank Group, Washington DC.
- Westphal, M. I., Hughes, G. A. & Brömmelhörster, J. 2013 *Economics of Climate Change in East Asia*. Asian Development Bank, Phillipines, p. 216.
- Wijngaard, R. R., Lutz, A. F., Nepal, S., Khanal, S., Pradhananga, S., Shrestha, A. B. & Immerzeel, W. W. 2017 [Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins](#). *PLOS ONE* **12**, e0190224.

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